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CITATION:

Kano, Taichi ...[et al]. Catalytic asymmetric syntheses of isoxazoline-N-oxides under phase-transfer conditions.. Chemical communications 2011, 47(15): 4358-4360

ISSUE DATE:

2011-04-21

URL:

http://hdl.handle.net/2433/156869

Catalytic asymmetric synthesis of isoxazoline-*N*-oxides under phase-transfer conditions

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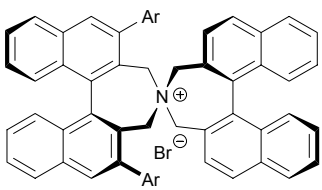
Received (in XXX, XXX) Xth XXXXXXXXX 200X, Accepted Xth XXXXXXXXX 200X
First published on the web Xth XXXXXXXXX 200X
DOI: 10.1039/b000000x

Catalytic asymmetric synthesis of various isoxazoline-*N*-oxides has been accomplished by asymmetric phase-transfer conjugate addition of bromomalonate to nitroolefins and subsequent ring-closing *O*-alkylation.

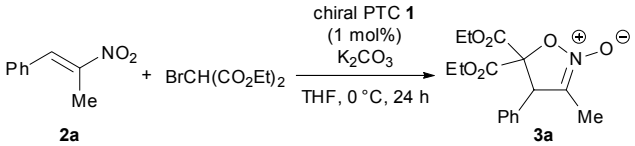
Isoxazoline-*N*-oxides serve as versatile building blocks for the preparation of complex molecules,[1] biologically active compounds and natural products.[2] While a number of synthetic methods have been developed to date,[3] there is still a need to expand synthetic approaches for their preparation. Chiral isoxazoline-*N*-oxides are known to be synthesized by using optically pure starting material[4] or stoichiometric amounts of a chiral reagent;[5] however, general methods for their preparation based on the catalytic asymmetric reaction are quite rare.[6] In this context, we have been interested in the development of a catalytic asymmetric synthesis of chiral isoxazoline-*N*-oxides through asymmetric phase-transfer conjugate addition and ring-closing *O*-alkylation.[7] Here we wish to report the efficient asymmetric synthesis of isoxazoline-*N*-oxides based on the asymmetric conjugate addition under phase-transfer conditions.



(*R*,*R*)-**1a** (Ar = 3,4,5-$F_3C_6H_2$)
(*S*,*S*)-**1b** (Ar = 3,5-^{t}Bu$_2$C$_6$H$_3$)
(*S*,*S*)-**1c** (Ar = 3,5-[3,5-$(CF_3)_2C_6H_3]_2C_6H_3$)
(*S*,*S*)-**1d** (Ar = 2-naphthyl)

We first examined the synthesis of isoxazoline-*N*-oxide **3a** by the reaction between diethyl bromomalonate and nitroolefin **2a** using 1 mol% of chiral PTC **1**[8] as catalyst and K_2CO_3 in THF (Table 1). Among the catalysts used, (*R*,*R*)-**1a** was found to be the most efficient catalyst for the present reaction, and the desired isoxazoline-*N*-oxide **3a** was obtained in excellent yield with moderate enantioselectivity (entry 1).

Table 1 Asymmetric synthesis of cyclic nitronate with **2a** and diethyl bromomalonate catalyzed by chiral PTC **1**.[a]

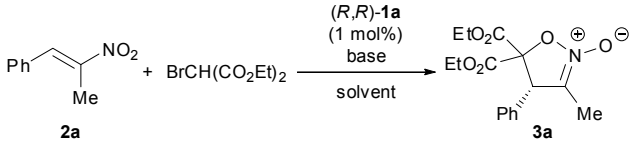


Entry	PTC	Yield (%)[b]	ee (%)[c]	Config
1[d]	(*R*,*R*)-**1a**	95	58	*S*
2	(*S*,*S*)-**1b**	87	46	*R*
3	(*S*,*S*)-**1c**	92	56	*R*
4	(*S*,*S*)-**1d**	73	30	*R*

[a] The reaction of **2a** (1 equiv) with diethyl bromomalonate (1 equiv) was carried out in THF in the presence of chiral PTC **1** (0.01 equiv) and K_2CO_3 (2 equiv) at 0 °C for 24 h. [b] Isolated yield. [c] Determined by HPLC analysis using chiral column (Chiralpak AD-H, Daicel Chemical Industries, Ltd.) [d] The reaction was performed for 7.5 h.

Having identified a suitable catalyst, the reaction conditions were then optimized, and the selected results were summarized in Table 2. When reactions were conducted in various solvents, mesitylene gave the highest enantioselectivity (entry 4). In an attempt to further improve enantioselectivity, lowering temperature was effective, although a longer reaction time was required (entry 5). Use of 70% aqueous Cs_2CO_3 as a stronger base successfully increased the reaction rate without loss of enantioselectivity (entry 6). When the reaction was performed at –35 °C for 12 h, the desired product was obtained in excellent yield with good enantioselectivity (entry 8).

Table 2 Asymmetric synthesis of cyclic nitronate with **2a** and diethyl bromomalonate catalyzed by (*R*,*R*)-**1a**[a]

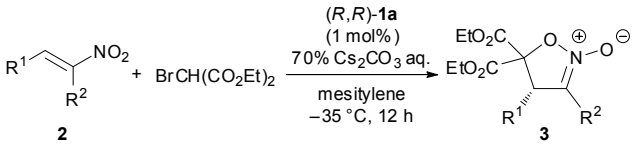


Entry	Base	Solvent	Conditions (°C, h)	Yield (%)[b]	ee (%)[c]
1	K_2CO_3	THF	0, 7.5	95	58
2	50% K_2CO_3 aq.	Et_2O	0, 8.5	84	63
3	50% K_2CO_3 aq.	toluene	0, 7.5	94	64
4	50% K_2CO_3 aq.	mesitylene	0, 7.5	83	70
5	50% K_2CO_3 aq.	mesitylene	–20, 24	80	77
6	70% Cs_2CO_3 aq.	mesitylene	–20, 2	70	79
7	70% Cs_2CO_3 aq.	mesitylene	–30, 8	97	81
8	70% Cs_2CO_3 aq.	mesitylene	–35, 12	95	83
9	70% Cs_2CO_3 aq.	mesitylene	–40, 12	29	77

[a] The reaction of **2a** (1 equiv) with diethyl bromomalonate (1 equiv) was carried out in a solvent in the presence of (*R*,*R*)-**1a** (0.01 equiv) and a base. [b] Isolated yield. [c] Determined by HPLC analysis using chiral column (Chiralpak AD-H, Daicel Chemical Industries, Ltd.)

With the optimal reaction conditions, the catalytic asymmetric synthesis of isoxazoline-*N*-oxides with several other nitroolefins **2** was examined (Table 3). The reaction of nitroolefin **2** having a primary alkyl group (R^2 = Et or Bu) at α-position gave the corresponding isoxazoline-*N*-oxide with good enantioselectivity (entries 2 and 3). On the other hand, the reaction of sterically demanding nitroolefin **2** (R^2 = *i*-Pr) proceeded slowly to give the product in lower yield and enantioselectivity (entry 4). We then investigated the effects of the β–substituent on nitroolefin **2**. The reaction of **2** having either electron-deficient or electron-rich phenyl group gave the corresponding isoxazolines in good yield and enantioselectivity (entries 6–8). Use of **2** with an alkyl substituent resulted in decreased enantioselectivity (entry 9).

Table 3 Asymmetric synthesis of cyclic nitronate with **2** with diethyl bromomalonate catalyzed by (*R*,*R*)-**1a**.[a]



Entry	R^1	R^2	Yield (%)[b]	ee (%)[c,d]
1	Ph	Me	95	83 (99)
2	Ph	Et	92	86
3	Ph	Bu	56	86
4[e]	Ph	*i*-Pr	63	77
5	Ph	Ph	97	81 (99)
6[e]	4-Br-C_6H_4	Et	84	85 (97)
7	4-NO_2-C_6H_4	Et	90	87
8[f]	4-MeO-C_6H_4	Et	84	87
9	Bu	Et	63	77

[a] The reaction of **2** (1 equiv) with diethyl bromomalonate (1 equiv) was carried out in mesitylene in the presence of (*R*,*R*)-**1a** (0.01 equiv) and 70 % Cs_2CO_3 aq. at –35 °C for 12 h. [b] Isolated yield. [c] Determined by HPLC analysis using chiral column (Chiralpak AD-H or Chiralcel OD-H, Daicel Chemical Industries, Ltd.) [d] Enantiomeric excesses in parentheses were obtained after a single recrystallization from cold ethanol. [e] The reaction was performed for 24 h. [f] The reaction was performed for 36 h.

The absolute stereochemistry of the obtained isoxazoline-*N*-oxide (Table 3, entry 6) was confirmed to be *S* by X-ray crystallographic analysis.[9] Based on the observed stereochemistry, a plausible transition state model can be proposed as shown in Figure 1. The chiral ammonium enolate, which is generated from diethyl bromomalonate and chiral phase-transfer catalyst (*R*,*R*)-**1a** under basic conditions, approaches the *Si* face of nitroolefin.

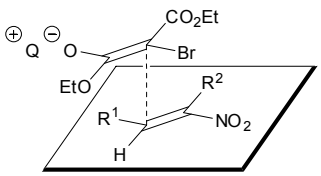
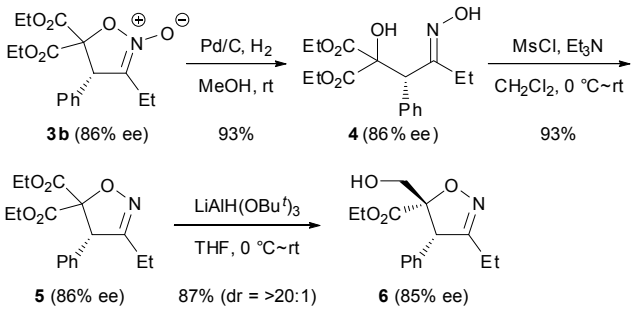


Fig. 1 Plausible transition state model.

The obtained isoxazoline-*N*-oxide was a useful intermediate in organic synthesis and readily converted to the corresponding oxime and isoxazoline (Scheme 1). When isoxazoline-*N*-oxide **3b** was treated with Pd/C in MeOH under H_2 atmosphere, oxime **4** was obtained in quantitative yield with complete retention of stereochemistry. Treatment of **4** with methanesulfonyl chloride and triethylamine in dichloromethane gave isoxazoline **5** in excellent yield without loss of optical purity.[10] Selective reduction of one ester group in **5** with lithium tri(*t*-butoxy)aluminium hydride gave mono-alcohol **6** exclusively.[11]



Scheme 1 Transformation of isoxazoline-*N*-oxide **3b**.

In summary, we have developed an efficient asymmetric synthesis of isoxazolidine-*N*-oxides by the asymmetric phase-transfer conjugate addition and the subsequent ring-closing *O*-alkylation. Further investigations to expand the substrate scope of this reaction are currently underway.

This work was supported by a Grant-in-Aid for Scientific Research from MEXT, Japan. We thank Mr. Masahiko Bando for X-ray crystallographic expertise, and Dr. Masakazu Nagasawa and Ms. Kayoko Yamamoto for mass-spectrometric analysis.

Notes and references

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† Electronic Supplementary Information (ESI) available: Experimental details. See DOI: 10.1039/b000000x/

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